Human Impact on Freshwater Environments in Norse and Early Medieval Myvatnssveit, Iceland

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Introduction

Zooarchaeological studies are currently being carried out at several Norse and early medieval farm sites in the Mývatnssveit district of northern Iceland (Fig. 1). All of the midden deposits investigated so far have contained the remains of several species of fish, including at least two freshwater species, brown trout (*Salmo trutta*) and arctic charr (*Salvelinus alpinus*), as well as varying quantities of marine taxa. The data indicate substantial differences in the importance of freshwater fish to the Norse and early medieval economy from one site to the next and over time. One possible environmental explanation for the temporal changes in the archaeofaunal record is that fish consumption varied according to the size of fish populations, which must ultimately have been determined at least in part by factors such as food availability and habitat quality. It is well established that the colonization of Iceland by the Norse brought large-scale change in terrestrial environments, with widespread deforestation (e.g. Hallsdóttir 1987) and soil erosion (e.g. Simpson *et al.* 2004). Could the Norse have wrought similarly profound changes on aquatic ecosystems? Here we review the functioning of the Mývatnssveit freshwater ecosystem and explore the evidence for pre-modern anthropogenic change.

Fig. 1. Location map showing Mývatnssveit, with Lake Mývatn and other sites mentioned in the text. The current position of the desert front is also shown.

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The freshwater ecosystems of Mývatnssveit

Mývatn is the third largest lake in Iceland at 37 km^2 and is largely groundwater-fed (Jónasson 1979a). The lake is shallow and eutrophic, with very high primary productivity by both planktic and benthic plants (especially algae), and consequently high secondary productivity, particularly by chironomids (Lindegaard and Jónasson 1979; Einarsson *et al.* 2002). Three fish species occur in Lake Myvatn: brown trout, arctic charr, and three-spined stickleback (*Gasterosteus aculeatus*), all of which feed on the invertebrate fauna. The stickleback is too small to be of economic importance to humans, but catches of the other two species typically range from 15,000 to 40,000 individuals per year (Gudbergsson 2004). Arctic charr usually dominate in Icelandic lakes, while trout are most abundant in river environments (cf. Snorrason *et al.* 1992).

The Laxá, a sizeable river with a discharge of around 40 $m^3 s^{-1}$ (Jónasson 1979b), flows out of Mývatn. The river is divided into two sections by the Laxárgljúfur canyon, 33 km downstream of Mývatn, a short but steeply inclined section of the river in which waterfalls prevent upstream movement of fish. Atlantic salmon (*Salmo salar*) are thus restricted to the lower section of the river. In the upper section, brown trout are the dominant fish species, although small populations of arctic charr and three-spined stickleback also occur (Steingrímsson and Gíslason 2002). The main food of the trout consists of blackfly (*Simulium vittatum*) and chironomid larvae, along with the gastropod *Radix peregra* (Steingrímsson and Gíslason 2002). Although the Laxá has a number of small tributaries, the food supply for the blackfly larvae in this part of the river consists mostly of organic particles derived from Mývatn, the concentration of which declines substantially downstream from the lake. The trout population in the Laxá, in terms both of numbers and size of individuals, is thus heavily dependent on the productivity of Mývatn (Gíslason 1994).

The Kráká, by contrast, is a much smaller (7 $m^3 s^{-1}$; Jónasson 1979b), spring-fed river with no significant input from lakes. It is colder than the Laxá, of which it is a tributary, and flows through sparsely vegetated terrain, so has few organic inputs through its course (Lindegaard 1979). Simuliids are rare, and the chironomid fauna is dominated by small, cold-adapted rheophilous species (Lindegaard 1979), so little food is available for fish. At present the Kráká has a high sediment load (*c.* 15 t d^{-1}) and a mobile, sandy substrate that is unfavourable for both diatom growth and trout spawning.

There also exist in Mývatnssveit a number of smaller lakes, most of which are shallow and oligotrophic, occupying glacial or lava-dammed basins. One such is Helluvaðstjörn (Fig. 1), from which a sediment core spanning the last ~3500 years has formed the basis of a palynological and palaeolimnological study.

Environmental change and freshwater ecosystems since *landnám*

Here we outline possible effects of human settlement on freshwater ecosystems in Mývatnssveit, based on our current understanding of the functioning of these systems.

1. Sediment supply

A major effect of anthropogenic disturbance on the aquatic system is likely to have been a substantial increase in sediment supply. At two archaeological sites in Mývatnssveit, Hofstaðir and Sveigakot, Simpson *et al.* (2004) found evidence that soil erosion rates increased after *landnám*. A major erosion front has been migrating northwards towards Mývatn from the interior desert since at least the later middle ages (Einarsson *et al.* 1988). Evidence from other parts of Iceland indicates that extensive soil erosion set in soon after *landnám* (e.g. Thompson *et al.* 1986; Hardardóttir 1999; Hardardóttir *et al.* 2001; Simpson *et al.* 2001), at the same time as an equally rapid reduction in the birch woodland as deduced from pollen data (Hallsdóttir 1987, 1996). Simpson *et al.* (2004) view the increase in soil erosion after *landnám* as an amplification of a natural, cyclical process of erosion and redeposition.

An increased supply of sediment affects aquatic systems in various ways. Shallow lakes and ponds may become shallower, or completely infilled. Sedimentation rates increased sixfold above the *landnám* tephra in the sequence from Helluvaðstjörn, at least some of which is attributable to increased inputs of allogenic sediment (i.e. reworked soil). On the other hand, sediment cores from the centre of Mývatn show little change in sedimentation rate – probably a result of the extremely rapid, mostly biogenic sedimentation in Mývatn which, at around 2 mm yr^{-1} (Einarsson *et al.* 2004), is about five times faster than in Helluvaðstjörn and would obscure any increase in allogenic sediment supply.

Increased soil inputs may also lead to a qualitative change in the substrate of lakes, ponds, and rivers. There is no evidence that this had an effect on the flora and fauna of either Helluvadstjörn or Mývatn, but the results were probably more serious in the Kráká. We speculate that the high modern

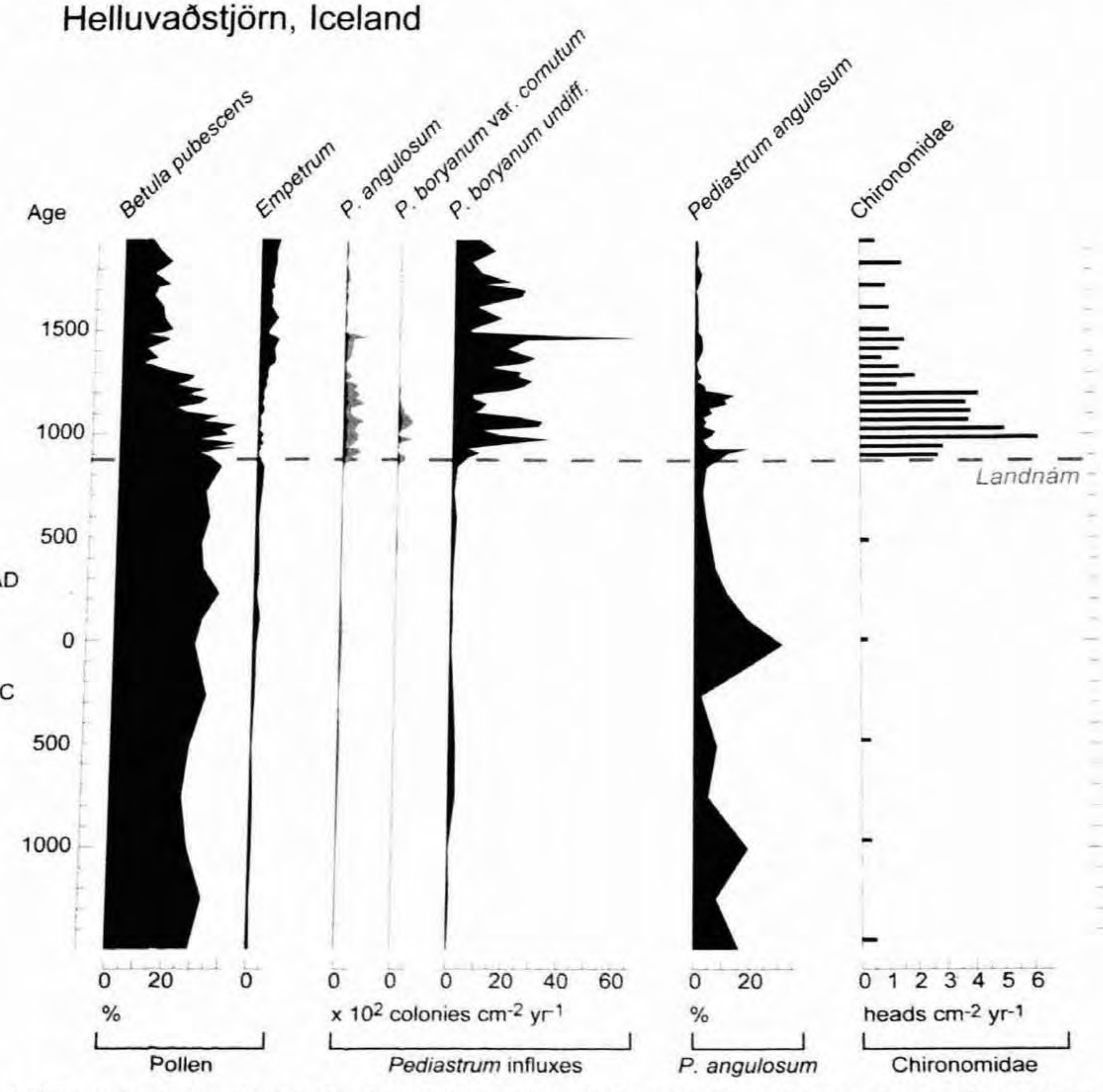

Fig. 2. Selected palaeoecological data from Helluvaðstjörn. Pollen percentage data are expressed as percentages of total land pollen. Pediastrum *data are expressed as flux of colonies cm-2 yr-1; grey curves for* P. angulosum *and* P. boryanum *var.* cornutum *are values exaggerated by a factor of five for clarity.* P. angulosum *is also separately expressed as a percentage of the total* Pediastrum *assemblages. Chironomid data are expressed as number of head capsules cm^{-2} yr^{-1}. All influxes are calculated using an age model based on tephrochronology.*

sediment load of the Kráká is likely to be of post-settlement origin. Reduction of bank vegetation and wider desertification along its course will have led to bank instability and increased sediment supply. This in turn will have destabilized the river bed, reducing the river's productivity. A reduction of bank vegetation will also have decreased the amount of organic litter entering the stream, at least altering, and possibly reducing, its invertebrate fauna.

2. Hydrological regime

Any decline in vegetation cover, together with loss of organic material from the soil, is likely to reduce the retention time of water in the soil, and result in a 'flashier' hydrology, i.e. one in which the fluvial response to a rainfall event is characterized by a small lag time and high amplitude. As well as increasing sediment transport rates and causing a shift to a coarser substrate, this may result in changes to the fauna as some fish species are deterred by high flow rates (cf. Jónasson 1979b). However, groundwater-controlled rivers such as the Kráká and Laxá today show a very steady hydrology, and are unlikely to have been considerably affected in this respect.

3. Nutrient dynamics

There are grounds for expecting that settlement would have brought an increase in the nutrient status of ponds and lakes. Deforestation is likely to have led to increased slopewash, with transport of soil organic matter into lakes; increased leaching by rainfall following deforestation would increase the nutrient status of soil water and groundwater entering lakes; airborne soil particles deposited in lakes may also have brought attached nutrients; while livestock and their dung could represent yet another mechanism of nutrient mobilization. This probably affected the aquatic fauna and flora, especially where they had approached equilibrium in nutrient-poor conditions.

The sediment sequence from Helluvaðstjörn has yielded empirical data which address this issue. Accumulation rates of *Pediastrum* algal colonies over the last ~3500 years, and the relative proportions of the three different taxa found, are shown in Fig. 2. Two important trends are apparent. Firstly, while *Pediastrum* accumulation rates are very low through most of the sequence, there is a substantial increase just above the base of the *landnám* tephra complex. This suggests that algal production in the lake increased immediately following the settlement, the most likely explanation being that this was due to an increase in nutrient input. Secondly, there is a shift in the relative proportions of the two most important taxa after *c.* AD 1200, with *Pediastrum angulosum* declining substantially relative to *P. boryanum* undiff. While most *Pediastrum* species are relatively cosmopolitan, *P. angulosum* is thought to prefer oligotrophic water (Nielsen and Sørensen 1992). Taken together, these changes suggest a trend towards increased nutrient availability since *landnám*.

Sub-fossil chironomid data from Helluvaðstjörn also show a substantial increase in population densities following *landnám*, suggesting a response to increased primary productivity. However, there is little change in species assemblages; it appears that the level of trophic change indicated by the increase in *Pediastrum* concentrations was not sufficient to affect the composition of chironomid communities, at least at the taxonomic level to which subfossils can be identified. The lake therefore probably experienced increased primary productivity following *landnám*, although not to the point of eutrophication, continuing until the 13th century AD, after which there is a slight decline in chironomid (and *Pediastrum*) population densities.

The coincidence of the increased productivity of both algae and chironomids in Helluvaðstjörn with the *landnám* tephra complex is suggestive of human agency. While a causal connection cannot be proven, anthropogenic impact seems the most likely explanation. The exact process involved – soil erosion, nutrient mobilization through the introduction of grazing herbivores, increased leaching following deforestation, or some other process – cannot be determined from the present data, but may be amenable to further investigation.

A complementary palaeolimnological record is available from Mývatn itself (Einarsson *et al.* 1993). Mývatn is atypical of Icelandic lakes in being naturally eutrophic due to groundwater inputs enriched in nutrients (Einarsson *et al.* 2004). Here, measurements of myxoxanthophyll, a pigment produced by planktonic cyanobacteria, in lake sediments dating to AD 990-1230 suggest that algal concentrations were not static on time scales of 10-100 years; two peaks in productivity occurred around AD 1040 and 1230. This indicates that primary productivity, and presumably therefore the size of fish stocks, were variable over time in Mývatn, possibly due to purely internal processes within the population dynamics of the ecosystem (cf. Einarsson *et al.* 1993, 2004). Chironomid data from Mývatn spanning the last 2000 years show no indication of increased population densities associated with *landnám*, and no other change in the fauna has been found that can be attributed to human activity in pre-modern times (Einarsson *et al.* 1988), but this is not surprising given that anthropogenic alterations of the nutrient budget would have to be very large to be detectable given Mývatn's high natural nutrient supply and large volume.

Further datasets from other lakes, ideally making use of more sensitive proxy indicators and depositional settings, will be required to determine how representative the present data are of the Mývatnssveit freshwater ecosystem as a whole. However, if the increase in primary productivity inferred from the Helluvaðstjörn record is valid and typical of other oligotrophic water bodies in the region, the increased productivity of previously highly oligotrophic lakes is likely to have had a positive effect on fish stocks in Mývatnssveit. Lake-dwelling fish – mostly charr – will have experienced an increase in their food supply as a secondary effect of enhanced primary production. Likewise, in those rivers that drain lakes, such as the Helluvaðsá (Fig. 1) and other tributaries of the Laxá, food availability for stream-dwelling trout will also have increased.

Freshwater resources and the zooarchaeological record

Preliminary zooarchaeological data showing stratigraphic changes are available from three contrasting sites in Mývatnssveit (Figs. 1 and 3): Sveigakot, a very early farm site with rich midden deposits spanning the late 9th to early 12th century AD and separable into three phases; Selhagi, which has midden deposits from the 10th to mid-12th centuries separable into two phases; and Hofstaðir, a high-status farm site, with two midden units of mid 10th, and 11th century age. The data hence encompass the period from the Norse *landnám* (*c.* AD 870) to the middle of the 12th century. Two patterns emerge from the archaeofaunal data. Firstly, freshwater fish are present at all three sites, although at Selhagi, marine fish become much more important over time, while at Hofstaðir, domestic mammals become more important. Secondly, among the freshwater taxa, the ratio of charr to brown trout increases through time at Selhagi.

A possible explanation of these data is the hypothesis that degradation of the aquatic environment caused a decline in freshwater fish populations, especially trout. This in turn could have resulted in a switch in fishing strategy to concentrate on charr, and increasing reliance on (presumably) more costly food resources such as farmed animals and imported marine fish. It is certainly possible that detrimental changes were taking place in parts of the aquatic ecosystem, but, as we have seen above, the palaeolimnological data suggest that productivity was not adversely affected by the settlement. In fact, the most important driver of aquatic productivity in Mývatnssveit – Mývatn itself – was apparently not affected by human impact to any significant degree in pre-modern times, although natural cycles in its productivity may have been significant on decadal and century time scales; while at Helluvaðstjörn, productivity actually increased.

If an explanation for the observed trends in the archaeofaunal data based on anthropogenic environmental change seems unlikely, a number of other possible explanations may be more appropriate. For example, the increasing importance of marine fish in the Selhagi archaeofaunal assemblages could be an indirect consequence of the conversion to Christianity in 1000 AD, which across Iceland spurred a trading economy in fish, which could be eaten on fast days when consumption of other meat was forbidden (Byock 2001: 53). Coastal fishing communities, such as Flatey in Skjálfandi, close to Mývatn and mentioned in the 13th century *Sturlunga Saga* (Jóhannesson *et al.* 1946: 158), provided a supply of saltwater fish for the domestic market, which the archaeofaunal record suggests included the farms of Mývatnssveit. Perhaps factors such as dietary preferences and the convenience of easily stored dried fish were also relevant. However, the decline in the proportion of all fish to domesticated mammal bones found at Hof-

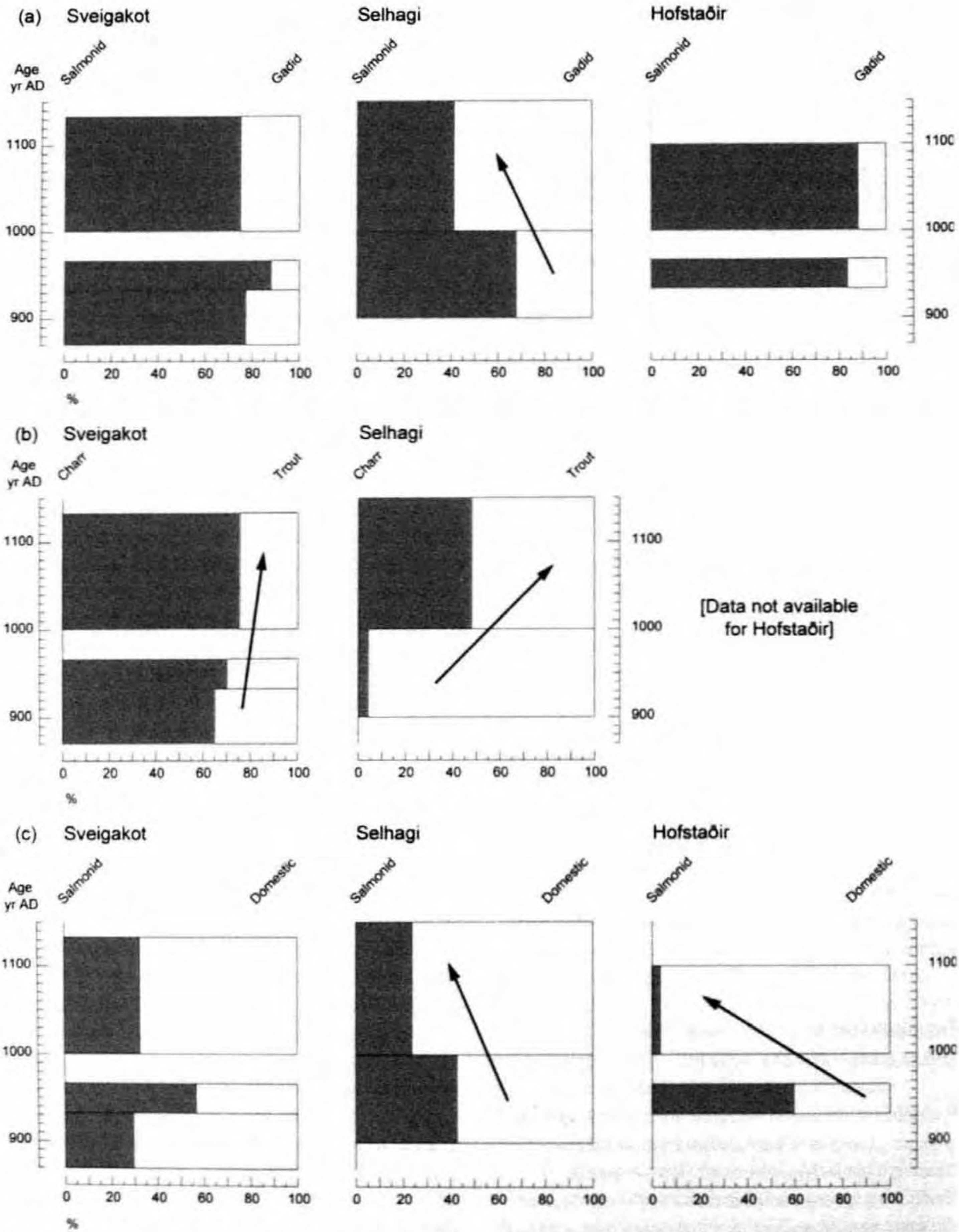

Fig. 3. Preliminary archaeofaunal data from stratified midden contexts at archaeological sites in Mývatnssveit. (a) Relative proportions of identified remains of members of the salmon family (Salmonideae) and cod family (Gadideae). (b) Relative proportions of arctic charr and brown trout (data not yet available for Hofstaðir). (c) Relative proportions of freshwater fish (charr and trout) and domestic mammals. Trends discussed in the text are indicated with arrows. All data are based on number of identifiable specimens.

staðir cannot be explained in this way. It may be that the relatively wealthy inhabitants of Hofstaðir could afford to eat fish on fast days and have mammal meat at all other times. Various social factors, such as changes in access rights to freshwater resources, or changes in fishing technology, may provide alternative explanations of the archaeofaunal data.

Conclusions

The impact of humans on the freshwater environments of Mývatnssveit probably covered a spectrum of severity. In some cases, such as completely infilled ponds and marshes, and perhaps in sensitive rivers such as the Kráká, the impact would have been very severe as the habitat was thoroughly modified to the detriment of fish populations. In other cases, such as in Mývatn itself where sedimentation rate and nutrient availability were already very high, humans appear to have had no detectable impact during the Norse and early medieval periods. More typically, however, the impact of humans on the aquatic environment was probably somewhere between these two extremes. At Helluvaðstjörn an increase in productivity is inferred to have taken place soon after *landnám*, which is likely, if anything, slightly to have increased the carrying capacity of the lake for fish.

The limited coverage of the palaeoecological data at present allows only tentative conclusions. However, it appears that human impact on the aquatic ecosystems of Mývatnsveit was not generally catastrophic, as it was in many terrestrial settings, and may even have been beneficial in places by causing fish stocks to increase. Natural change, especially the cyclicity inherent in the population dynamics of freshwater ecosystems, and social factors, may have been of greater importance in determining the position of freshwater resources in the economy of the Norse and early medieval periods.

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